Comparison of reactor core performance with low and high recycling divertor target plasmas using the ONETWO code

T. Evans, C. Wong
General Atomics, San Diego, CA 92186

and

T. Rognlien
LLNL, Livermore CA 94551

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ALPS related modeling tasks at General Atomics

Kinetic Impurity Transport modeling

- **Monte Carlo Impurity (MCI) transport modeling of:**
  - **solid and liquid lithium DiMES sample exposures in DIII-D** (T. Evans, R. Maingi at ORNL and J. Brooks at ANL)
  - **lithium thermalization in 2D slab for UEDGE fluid code SOL simulations** (T. Evans, D. Finkenthal, and T. Rognlien at LLNL)

Atomic Data Resources

- **Provide up-to-date atomic data, such as lithium and tin ionization rates, needed for ALPS modeling.** (T. Evans)

Reactor Systems Studies ←

- **Couple low recycling UEDGE SOL solutions to the ONETWO core transport code. Use the ONETWO core profiles in GA's reactor systems codes to assess fusion performance in a reactor with liquid metal divertor targets.** (T. Evans, C. Wong, and T. Rognlien at LLNL)

ALPS reactor systems studies
Overview and Status

Goal

- Assess the impact of liquid divertors on fusion reactor performance and cost of electricity (COE).

Approach

- Simulate SOL plasmas with low and high recycling target plate conditions in an ITER-like geometry using the UEDGE fluid code.

- Couple the UEDGE solutions to 1 1/2 D core transport simulations using the ONETWO code and search for stable core profiles with both low and high recycling SOL solutions.

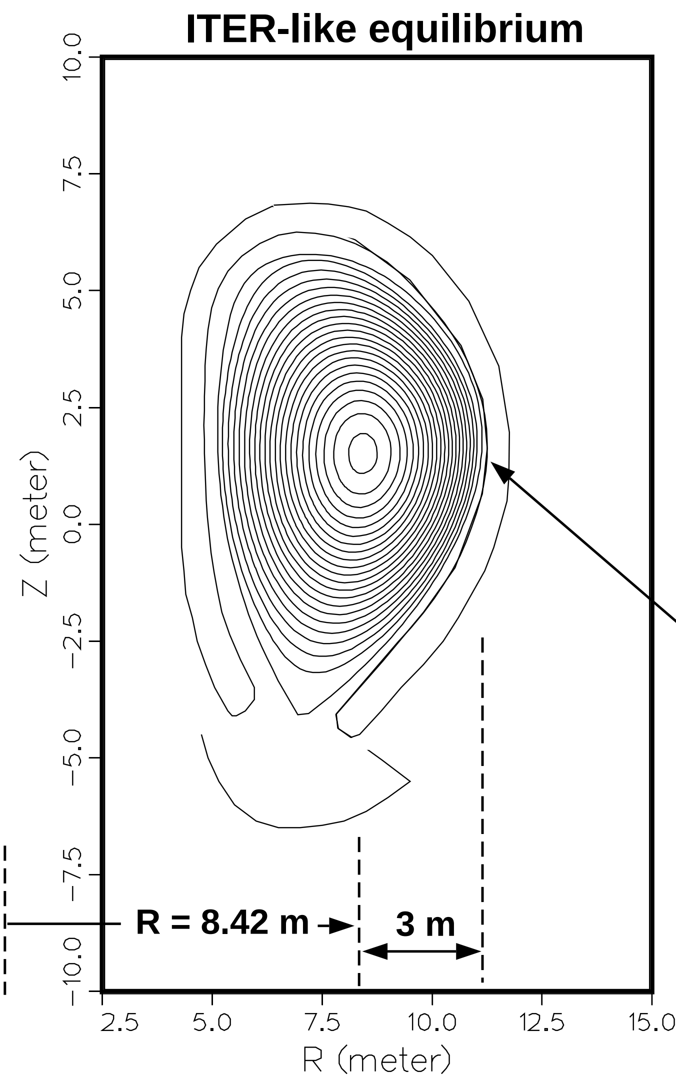
- Use the stable ONETWO core solutions in a reactor systems code to assess ITER-like reactor performance, current drive efficiency, and COE for low recycling lithium targets and high recycling solid/flibe targets.

Status

- UEDGE high and low recycling solutions were successfully coupled to ONETWO and stable solutions were found with operating points ranging between $Q_{DT} = 58.2$ and $Q_{DT} = 115.7$.

- Preliminary systems code runs have been completed for ITER-like reactor performance evaluations, using ONETWO core profiles, and have shown a potential COE reduction for the low recycling case.

ITER-like reactor parameters were used for the initial systems studies



B_T = 6.05 T, I_p = 25 MA,

R = 8.42 m, a = 3 m,

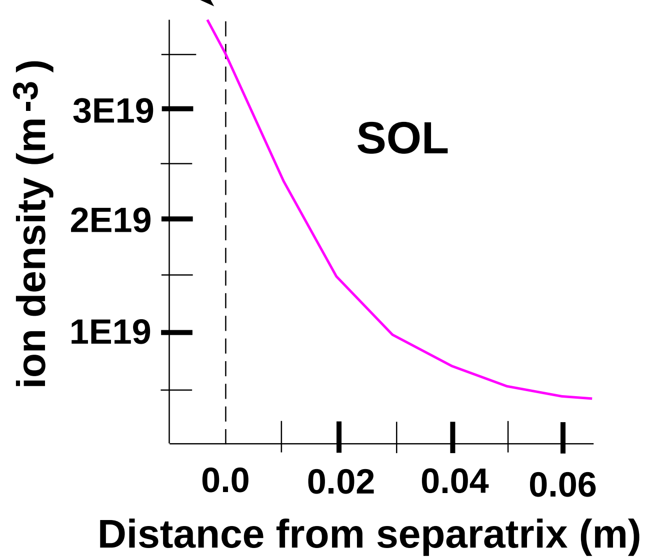
elongation = 1.64,

volume = 2.11×10^3 m^3,

fast wave heating (no NBI),

q_a = 5.1

Couple UEDGE SOL solutions to ONETWO at the midplane separatrix.



Low recycling ion density from UEDGE at outer midpalne

Coupling Parameters

Low recycling	High recycling
n_i = 3.5E19	n_i = 4.7E19
L_i = 0.29 m	L_i = 0.03 m
T_i = 310 eV	T_i = 400 eV
T_e = 250 eV	T_e = 220 eV

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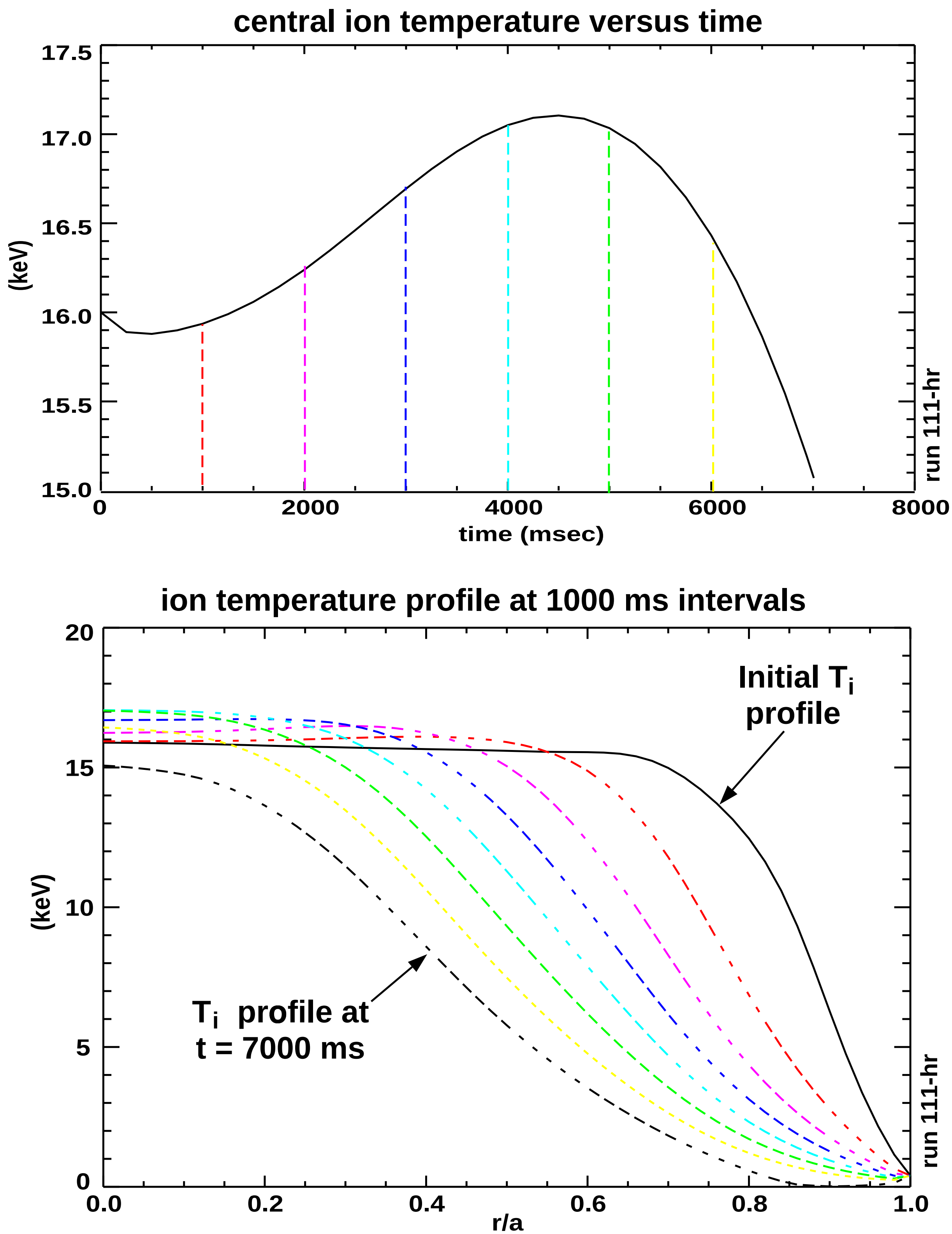
Initial pedestal transport model resulted in a thermal collapse of the edge



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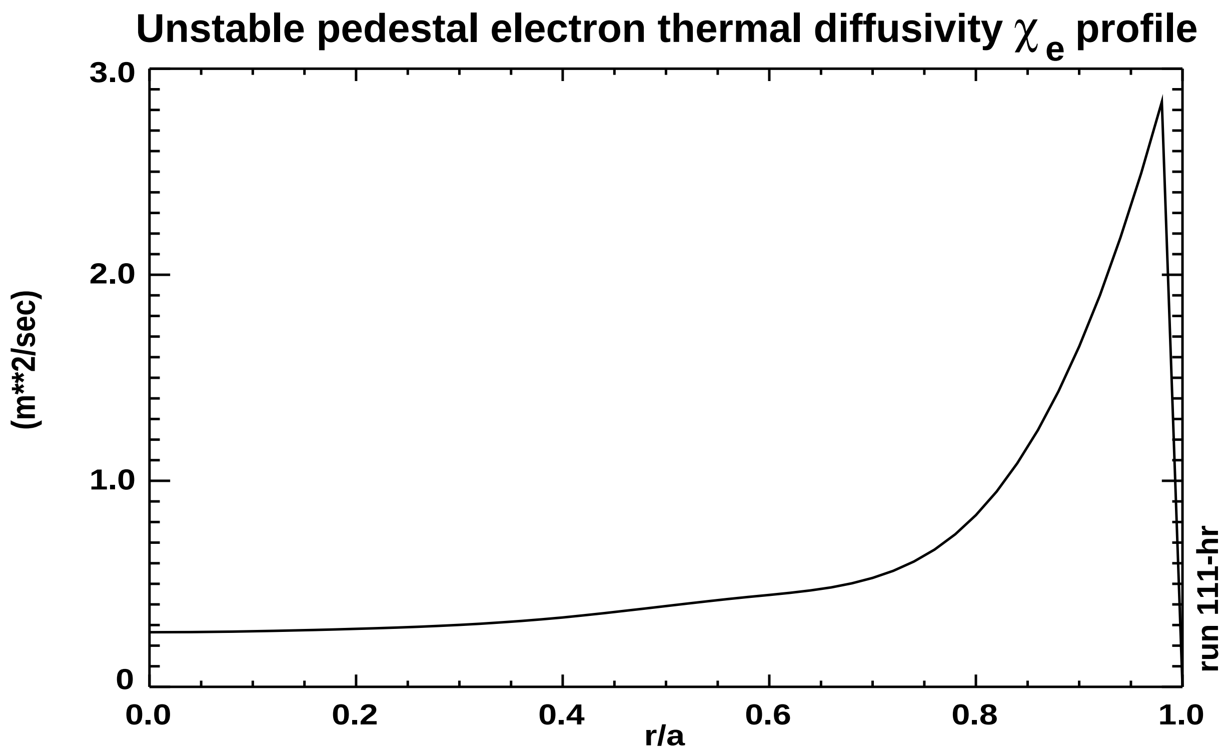
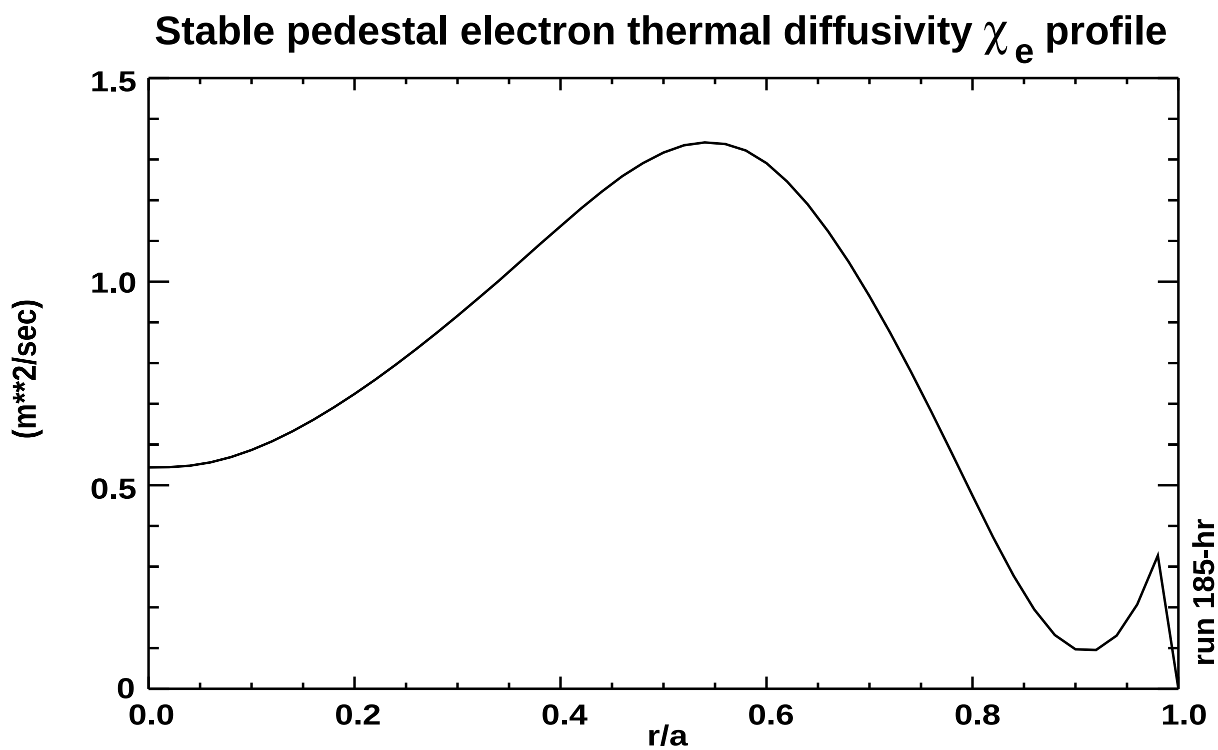
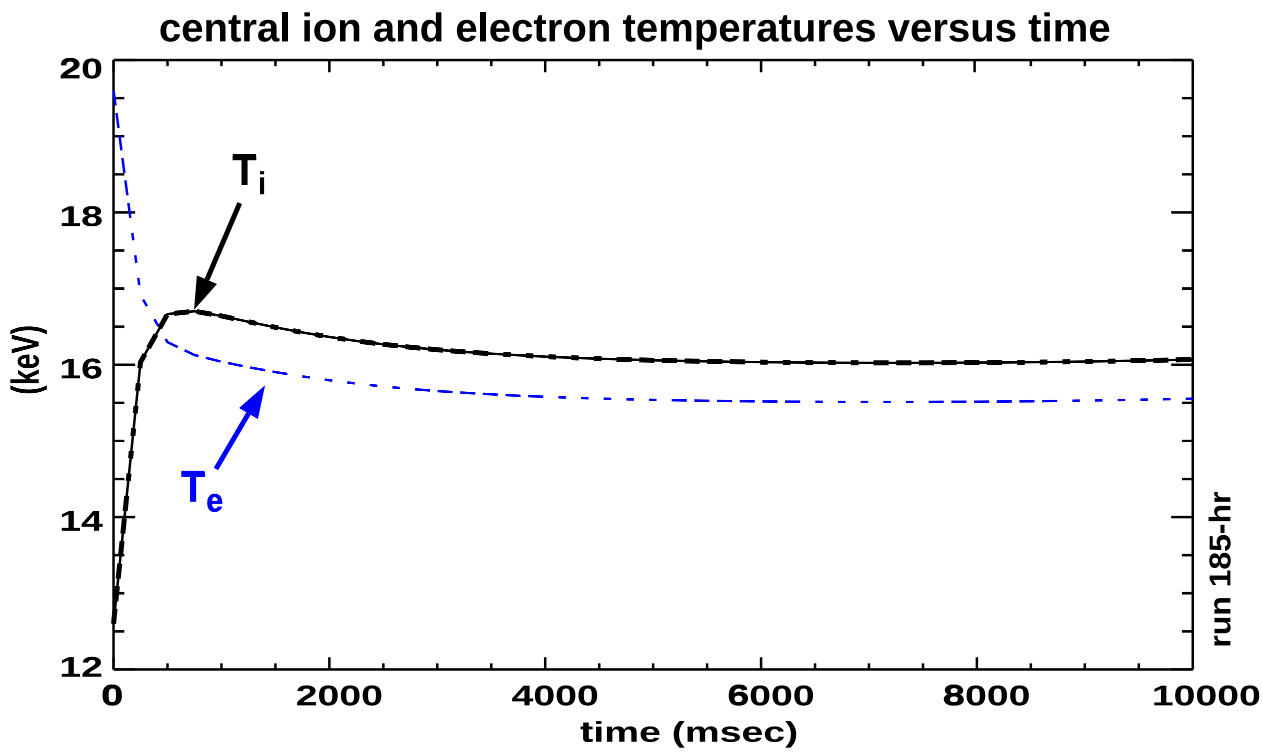
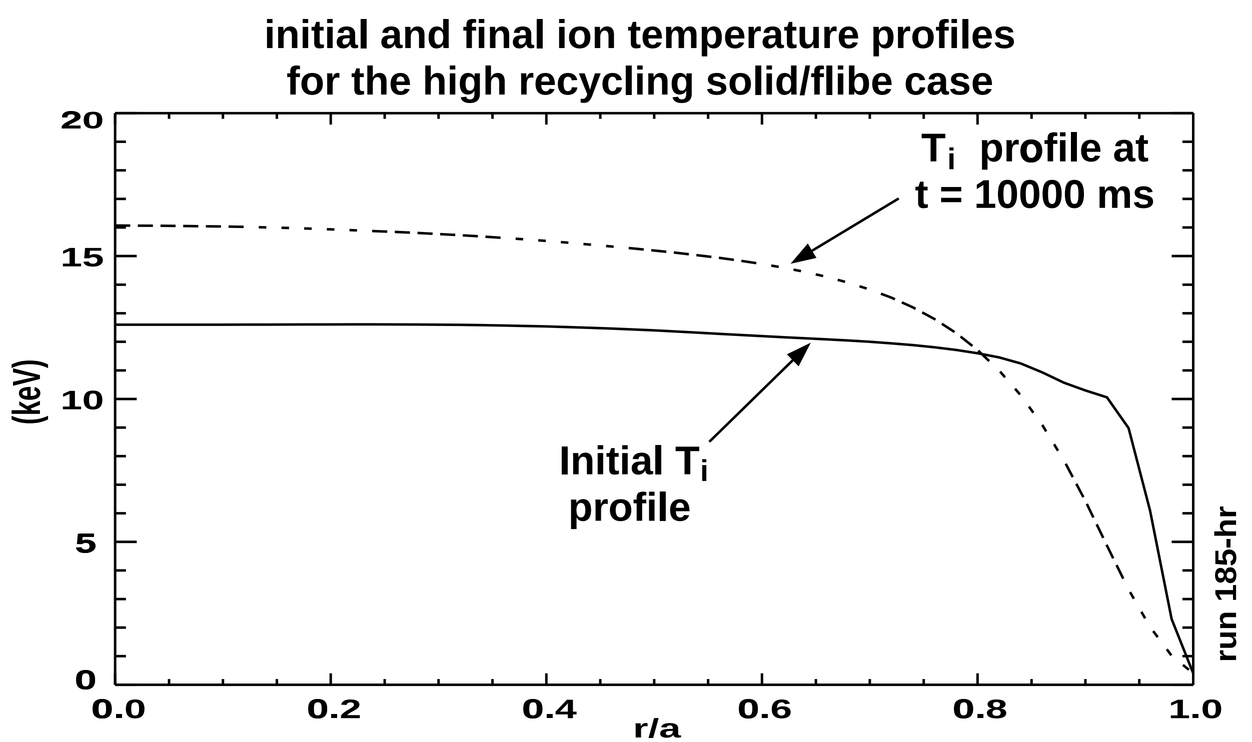
Radiatively stable solutions were obtained with reduced pedestal thermal diffusivities





Stable high recycling solutions are obtained with reduced pedestal transport





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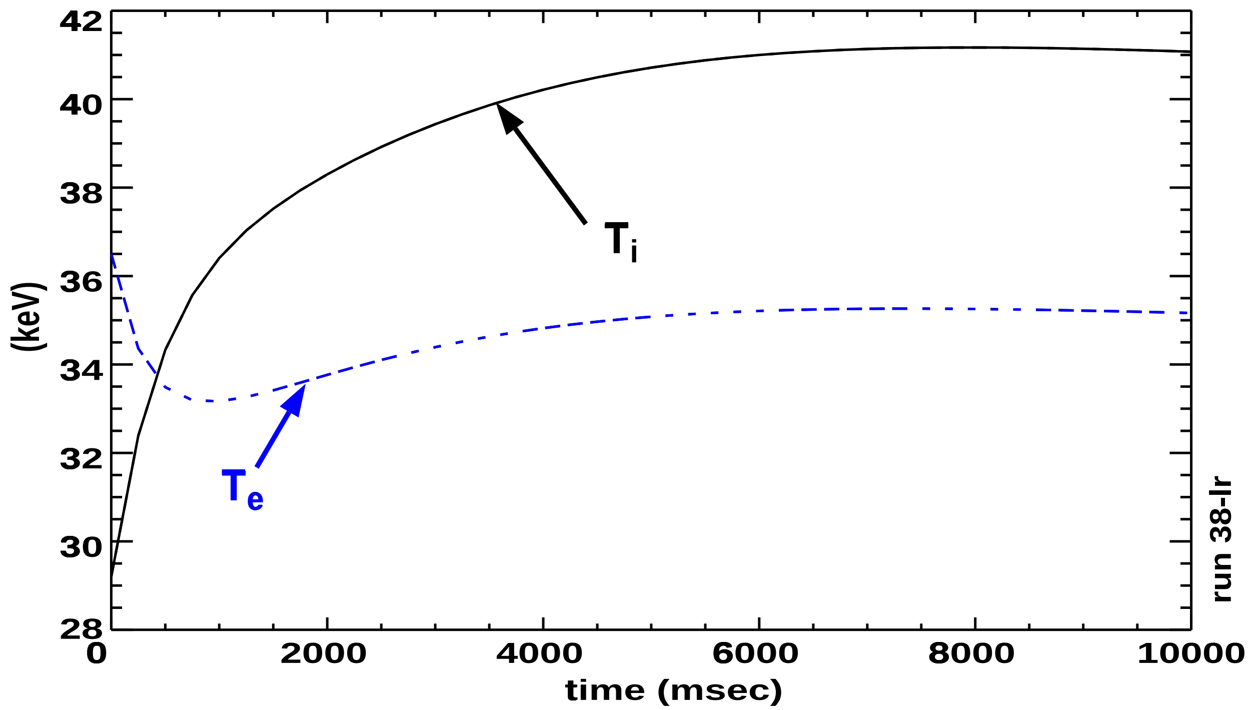
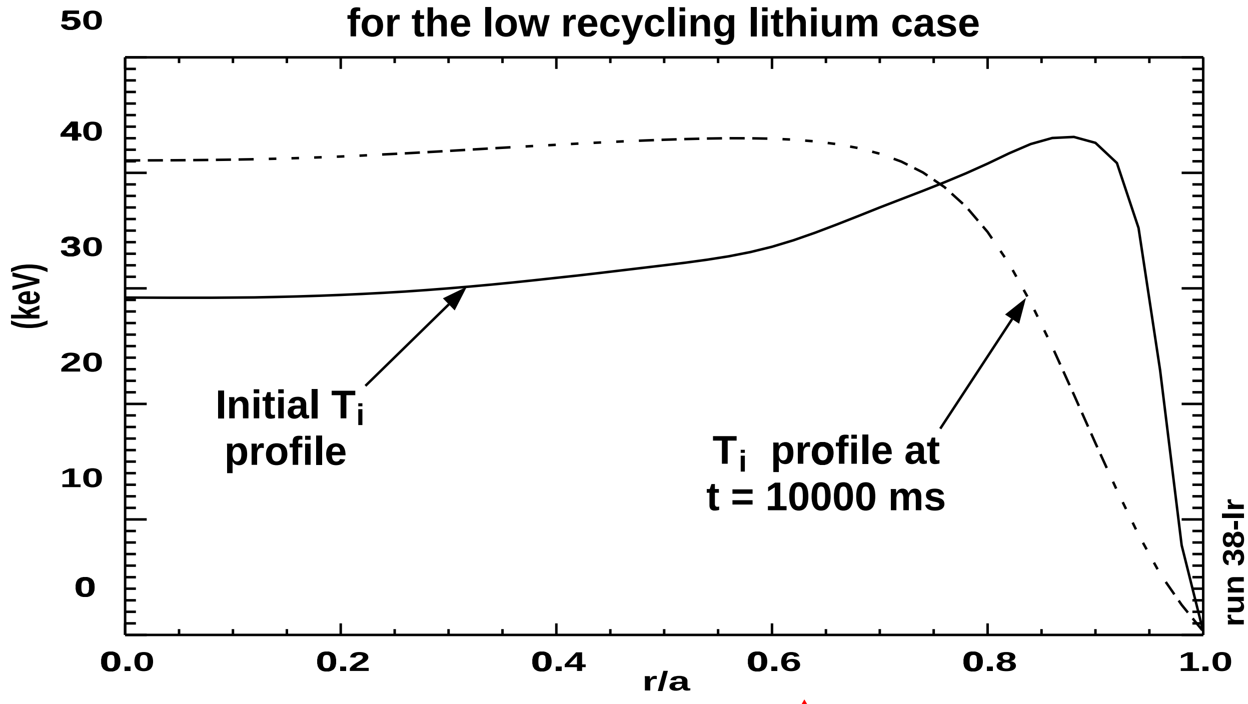
Low recycling solutions are obtained with the same $\chi_{e,i}$ profiles as for high recycling

central ion and electron temperatures versus time



initial and final ion temperature profiles
for the low recycling lithium case



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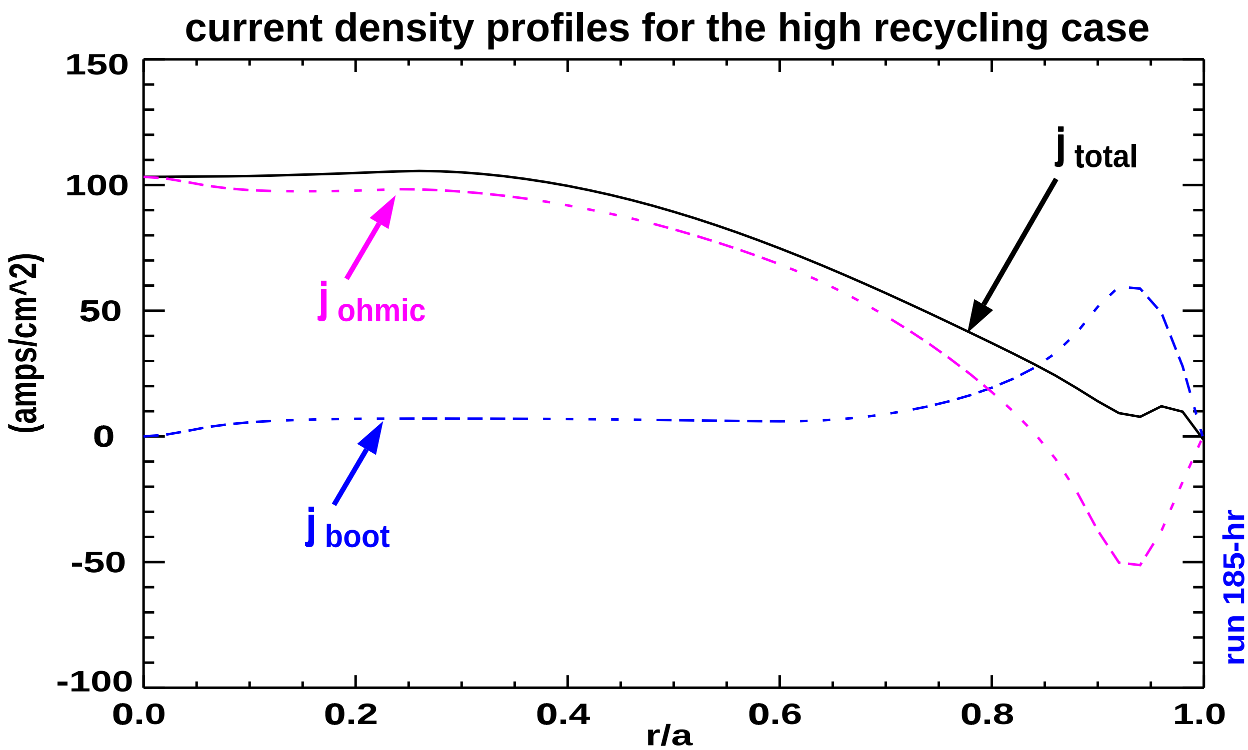
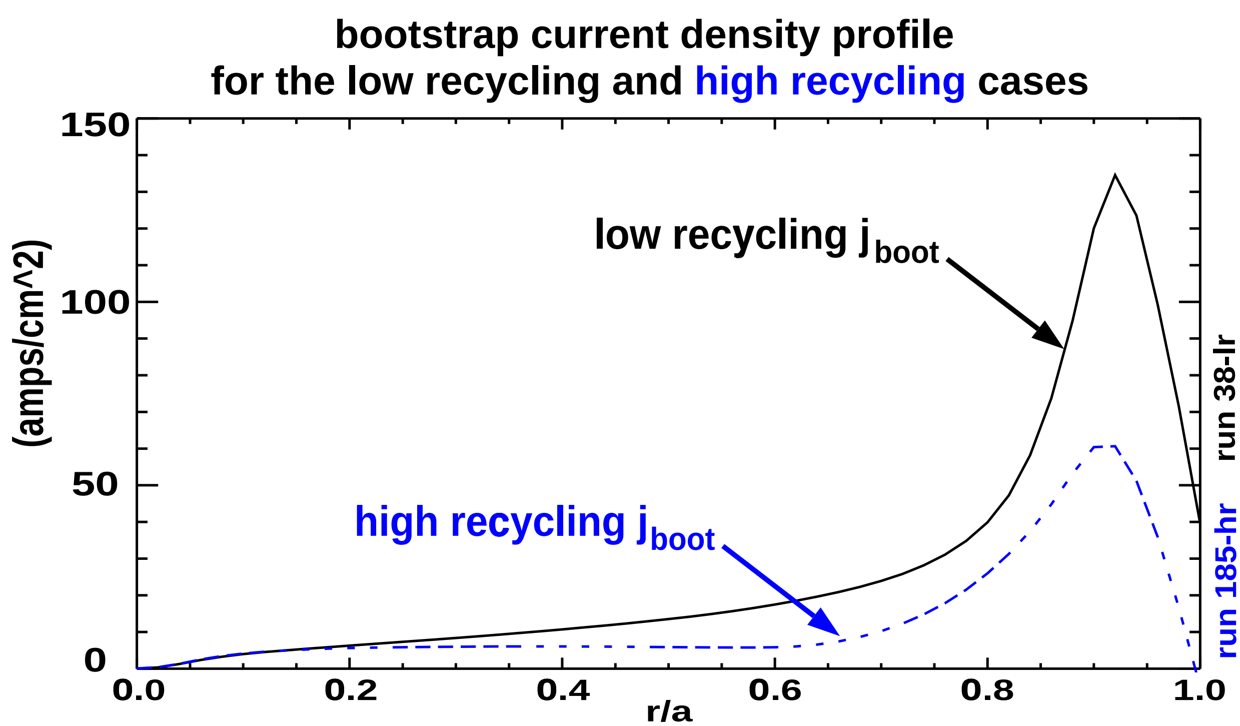
Edge bootstrap current density increase in the low recycling case may be unstable





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Initial ONETWO result suggest improved performance for the low recycling case

	High Recycling Case (solid/flibe)	Low Recycling Case (lithium)
$T_e(0)$	15.6 keV	35.1 keV
T_i (0)	16.1 keV	41.1 keV
$n_e(0)$	2.31 X 10^{20} m^{-3}	2.09 X 10^{20} m^{-3}
P_{in_tot}	336.8 MW	487.0 MW
P_{fw_in}	12.0 MW	12.0 MW
P_{fw_abs}	9.03 MW	10.1 MW
τ_E	3.38 s	5.09 s
H(89p)	2.22	3.67
I_{fw}	109 kA	90.2 kA
I_{boot}	7.2 MA	16.4 MA
D-D neutrons	2.06 X 10^{18} s^{-1}	7.72 X 10^{18} s^{-1}
Q_{DT}	58.2	115.7

Althought these preliminary results appear promising

- The core/pedestal transport physics, fueling, impurity content, and pedestal-SOL coupling assumptions being used in these simulations require additional testing, and
- The MHD stability of these solutions needs to be evaluated.

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Summary of high and low recycling ITER-like core-SOL coupling studies

Comments on transport and stability

- Stable solution could not be obtained using ITER-like $\chi_{e,i}$ profiles scaled from ITER similar plasmas in DIII-D.
- Transport coefficients used to obtain radiatively stable pedestal profiles in the high recycling case also produced stable low recycling pedestal profiles.
- Addtional studies are required to determine the uniqueness of the solutions.
- The approach used provides acceptable core solutions but significant effort is required to identify stable solutions when either the transport model or the boundary conditions change.

Comments on preliminary reactor performance results

- Physics based pedestal transport models have yet to be tested.
- Core and pedestal impurity effects should be modeled.
- Edge MHD stability needs to be examined.

System analysis of High and Low Recycling 1996 ITER Design (Preliminary results)

Clement Wong, Todd Evans, Tom Rognlien

General Atomics and LLNL

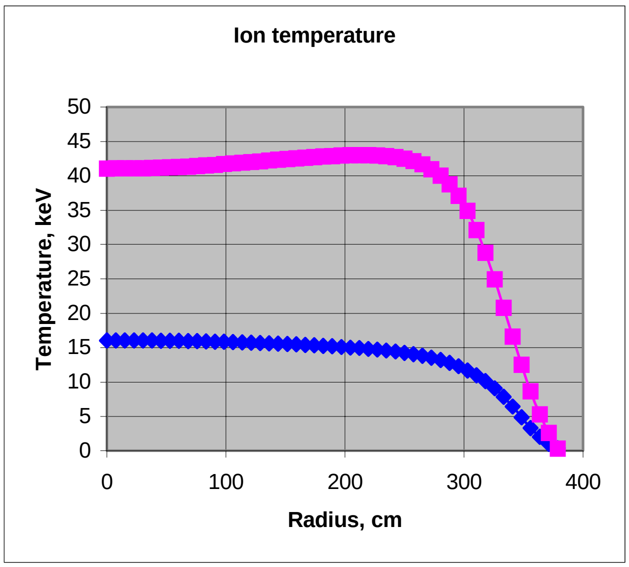
Procedure

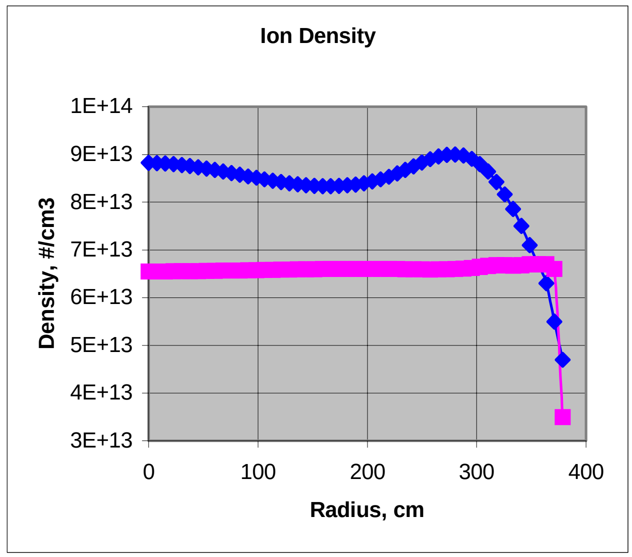
- Curve fitted to High Recycling(ni, ne, Ti, Te), and Low Recycling(ni, ne, Ti, Te), results from ONETWO
- Set up 1996 ITER design geometry
- Bench-marked 1996 ITER 1.5GW fusion physics parameters
- Matched ni and Ti peaking factors from ONETWO for high and low recycling cases
- Input bootstrap fractions and adjust βN to match peak ion densities
- Evaluate cases with and without carbon impurity
- Obtained fusion power and other physics parameters
- Calculated normalized reactor COE (based on ARIES system code methodology)

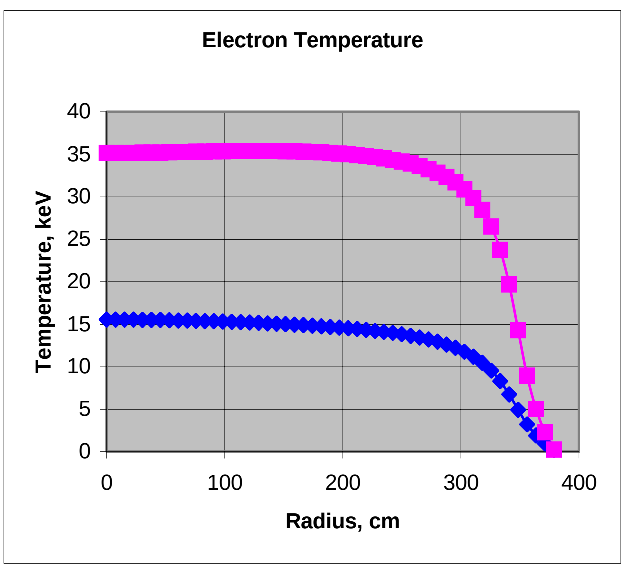
ALPS meeting, ANL May 2000

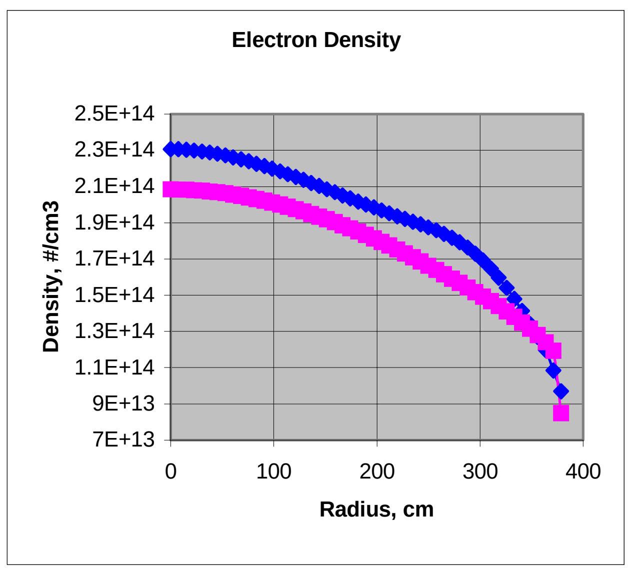
High and Low Recycling Temperatures and Densities
(Fitted to ONETWO results)

$$\mathrm{Ti}(x) := \frac{15.705}{\left(1 + 3.549\,10^{-6}\cdot e^{14.563x}\right)}$$









1996 ITER Geometry

Major radius, m	8.14
Minor radius, m	2.8
Elongation	1.64
Triangularity	0.25
Bt, T	5.68
Plasma volume, m^3	1938
First wall area, m^2	1281

System Code Preliminary Results

	1996 ITER[1]	High Recycling	Low Recycling
βN	2.935	2.121	4.6
βtotal, %	2.8	3.1	6.3
Plasma current, MA	15.4	23	21
Bootstrap fraction	0.6	0.288	0.656
Peak ni, #*$10^{20}/m^3$	0.664	0.868	0.676
Peak Ti, keV	20	15.7	42
Pα, MW	303	375	701
Pfusion, GW	1.52	1.87	3.5
Zeff, W/WO carbon	1.58	2.75/1.175	3.0/1.117
Pfwcd/PNBcd, MW	7.32	12[2]/33.3	12[2]/4.3
Rad. Power, W/WO carbon	41.6	380/297	700/250
FW ϕ, MW/m^2	0.167	0.304/0.29	0.556/0.42
Γn, MW/m^2	0.947	1.171	2.189
Pth, GW	1.68	2.1	3.9
Pe-gross, MW @ηth=33%	553	603/695	1174/1277
Recirculating Pe, MW	66.8	84/137	108/88
Pe-net, MW	487	603/558	1174/1190
Normalized total COE	1	0.87/0.95	0.58/0.57

[1]Simulated 1996 ITER design aiming for a fusion power output of 1.5 GW

[2]Input parameter

Observations

- **We completed the first iteration of combined UEDGE, ONETWO and System code analysis of high and low recycling cases of the 1996 ITER design.**

- **UEDGE results indicate high-density gradient at the edge for the low recycling option.**

- **Stable ONETWO results indicate higher temperature and lower density for the low recycling option, but pedestal and MHD physics need to be verified.**

- **Differences in input assumptions and corresponding impacts to ONETWO and system code results need to be understood and resolved.**

- **Core carbon impurities will have impact on reactor performance. But the low recycling case should not have carbon as impurity.**

- **Preliminary results show that the low recycling option has an advantage in total COE over the high recycling 1996 ITER design. Further evaluation is needed.**

Proposed Key Tasks for the Next Iteration

System study

- **Input core radiation as a function of plasma temperature**
- **Include self-consistent determination of helium impurity fraction**

ONETWO

- **Implement more physics based modeling of core transport coefficients**
- **Examine implications of ONETWO results on pedestal and MHD equilibrium physics**
- **Couple UEDGE solution to GATO and BALOO in order to examine MHD stability**
- **Coupled with system code calculations to determine current drive efficiency and requirements**

Work with LLNL to initiate the next iteration of the combined UEDGE, ONETWO and System Code evaluation